

# About neutral mesons and particle oscillations in the light of field-theoretical prescriptions of Weinberg

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The postulated universality of the Weinberg's prescriptions on the diagonalization of the mass term of the Lagrangian without increasing the total number of entities leads to the following conclusions: the set of neutral  $K$ -mesons consists of two elements,  $K_S^0$  and  $K_L^0$ ; the states  $K^0$  and  $\bar{K}^0$  do not exist as physical objects (in the form of particles or "particle mixtures"); the absence of the states  $K^0$  and  $\bar{K}^0$  destroys grounds for introducing the notion of their oscillations. The conclusions concerning the neutral  $K$ -mesons are also applicable to the neutral  $D$ -,  $B$ - and  $B_s$ -mesons. A theoretical and experimental vulnerability of the neutrino oscillation concept is noted.

The initial judgments about the family of four neutral  $K$ -mesons still remain almost unchanged and, furthermore, extend on the families of neutral  $D$ - and  $B$ -mesons. The concept of mutual transition of  $K^0$ - and  $\bar{K}^0$ -mesons in vacuum, originated long ago and retained up to present day, has served initially [1] and continues to serve now [2] as the only theoretical argument in favor of the hypothesis of neutrino oscillations by analogy with the letter.

In the present paper, we propose to put the status of neutral  $K$ -mesons in full accordance with field-theoretical prescriptions of Weinberg [3] that have led to the prodigious gauge theory of electroweak interactions by making use of the diagonalization of the mass term in the Lagrangian without increasing the total number of entities. The specified prescriptions are an exact realization of general scientific principle existing for hundreds of years that "entities must not be multiplied beyond necessity", which, having been accepted as a universal rule of field theory and particle physics, inevitably eliminates any reason for the meson oscillation.

For further comparisons, we focus on particular steps of Weinberg's procedure [3] on eliminating the item  $cA_\mu^3(x)B^\mu(x)$  ( $c$  is a constant) in the Lagrangian mass term, which is nondiagonal on the initial gauge fields and appears due to Higgs mechanism of spontaneous breaking of the original symmetry. This item could serve as the reason for the judgment on the possibility of a transition of one field to another in vacuum. First step: on the basis of two suitable superpositions of classical fields  $A_\mu^3(x)$  and  $B_\mu(x)$ , Weinberg introduces orthonormal classical fields with definite masses  $Z_\mu(x)$  and  $A_\mu(x)$ . Second step: Weinberg expresses the fields  $A_\mu^3(x)$  and  $B_\mu(x)$ , and then all terms of the gauge Lagrangian, through the fields  $Z_\mu(x)$  and  $A_\mu(x)$ . Third step: Weinberg gives status of quantized fields to the fields  $Z_\mu(x)$  and  $A_\mu(x)$  and identifies them with such particles as the intermediate meson  $Z$  and the photon. First note: at any stage of constructing the gauge model, Weinberg does not connect the fields  $A_\mu^3(x)$  and  $B_\mu(x)$  with any quanta. Second note: the original gauge field  $A_\mu^3(x)$  and  $B_\mu(x)$  that serve as the cornerstone in the Weinberg's construction disappear in the final model of electroweak interactions. Third note: the initial fields possess well-defined values of weak isospin and its third projection, but the final fields  $Z_\mu(x)$  and  $A_\mu(x)$  do not have such definite values, and, therefore, the corresponding terms of the electroweak interaction Lagrangian violate the isospin symmetry.

We now turn to a number of current opinions about the neutral  $K$ -mesons. They mainly reproduce part of the judgments stated in the works by Gell-Mann [4] and Gell-Mann and Pais [5] with adding some corrections for the results of the subsequent experiments concerning the violation of  $CP$ -symmetry.

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Starting from the assumption of strict conservation of the isotopic spin in strong interactions, Gell-Mann [4] concludes that, among the two long-lived neutral particles produced in the collision of the  $\pi^-$ -meson with the proton, one particle ( $K^0$ ) is a boson with the isospin  $1/2$  and its projection  $-1/2$  and that there exists an antiparticle ( $\bar{K}^0$ ) with the isospin projection  $+1/2$  which corresponds to the boson  $K^0$  and is different from it. The mentioned assumption of Gell-Mann is the key element in the subsequently formed structure of the family of neutral  $K$ -mesons.

Gell-Mann and Pais [5] consider that, if there exists the decay  $K^0 \rightarrow \pi^+ + \pi^-$ , then there should exist the charge-conjugate process  $\bar{K}^0 \rightarrow \pi^+ + \pi^-$ , and thus, the weak interaction causes the virtual transition  $K^0 \rightleftharpoons \pi^+ + \pi^- \rightleftharpoons \bar{K}^0$ . The last judgment and the aspiration for providing the  $C$ -parity conservation in weak decays lead to the introduction of the quanta  $K_1^0$  and  $K_2^0$ , which fields are expressed in the form of normalized sum and difference of the fields  $K^0$  and  $\bar{K}^0$ , respectively. According to Gell-Mann and Pais,  $K^0$  and  $\bar{K}^0$  are the primary objects in production phenomena, whereas the decay process is best described in terms of  $K_1^0$  and  $K_2^0$ . Each of the latter can be assigned a definite lifetime, that is not true to the  $K^0$  and  $\bar{K}^0$ .

Note that a long-lived neutral boson produced, for example, in the collision of a  $\pi^-$ -meson with a proton, cannot make any experimental manifestation between the production moment and the decay moment and, consequently, it does not allow experimental identification in this time interval. The opinion stated in [4] and [5] that such a boson must have a well-defined value of the isospin and its third projection remains nothing more but an assumption. The fact that the introduced hadrons  $K_1^0$  and  $K_2^0$  do not possess definite values of the third projection of the isospin, does not induce Gell-Mann and Pais to reconsider their assumption of strict isotopic spin conservation in strong interactions, and this essentially prohibits the participation of these hadrons in strong interactions, causing at least a surprise.

Essential is the position of the authors of work [5] about reserving the word "particle" for an object with a definite lifetime and recognizing the quanta  $K_1^0$  and  $K_2^0$  as true "particles", and about that the  $K^0$  and  $\bar{K}^0$  must, strictly speaking, be considered as "particle mixtures" is presented essential. The mathematical definition of "particle mixtures" has resulted by Pais and Piccioni [6] in introducing and describing the concept of oscillations, mutual transitions of the  $K^0$  and  $\bar{K}^0$ -mesons in vacuum.

Let us now present a view of the neutral  $K$ -mesons obtained on the basis of exactly applying to them the field-theoretical prescriptions of Weinberg on the diagonalization of the mass term in the Lagrangian without increasing the total number of entities.

Following Weinberg, we shall deal initially not with particles but with suitable classical fields and assume that the initial Lagrangian of strong interactions is invariant under transformations of the isospin group  $SU(2)$  (or the internal symmetry group  $SU(3)$ ).

We introduce two neutral fields  $\Phi_{+1\frac{1}{2}-\frac{1}{2}}(x)$  and  $\Phi_{-1\frac{1}{2}+\frac{1}{2}}(x)$  that are pseudoscalar under the orthochronous Lorentz group and possess strangenesses  $\pm 1$ , isospin  $1/2$  and its projections  $\mp 1/2$  (these fields can also be considered as the components of vectors in the octet representation space of the group  $SU(3)$ ).

We assume at the stage of preliminary analysis that, in the absence of weak interactions, these fields could describe the lower bound states of quark-antiquark systems, respectively,  $d\bar{s}$  and  $s\bar{d}$ . In the presence of weak interactions, these two systems would virtually pass into one another due to double exchange of  $W$ -bosons with changing the third projection of isospin and strangeness. (Feynman diagrams corresponding to such an exchange can be found in the monograph [7]). This means that the mass term in the Lagrangian of fields  $\Phi_{\pm 1\frac{1}{2}\mp\frac{1}{2}}(x)$ , in view of the influence of weak interactions, should be presented in the following form

$$\begin{aligned} \mathcal{L} = & -m_+^2 \Phi_{+1\frac{1}{2}-\frac{1}{2}}^*(x) \Phi_{+1\frac{1}{2}-\frac{1}{2}}(x) - m_-^2 \Phi_{-1\frac{1}{2}+\frac{1}{2}}^*(x) \Phi_{-1\frac{1}{2}+\frac{1}{2}}(x) \\ & - a \Phi_{+1\frac{1}{2}-\frac{1}{2}}^*(x) \Phi_{-1\frac{1}{2}+\frac{1}{2}}(x) - a^* \Phi_{-1\frac{1}{2}+\frac{1}{2}}^*(x) \Phi_{+1\frac{1}{2}-\frac{1}{2}}(x), \end{aligned} \quad (1)$$

where  $m_+$  and  $m_-$  are real constants.

If the mass term of Lagrangian (1) does not change under the transformation  $\Phi_{\pm 1\frac{1}{2}\mp\frac{1}{2}}(x) \rightarrow \Phi_{\mp 1\frac{1}{2}\pm\frac{1}{2}}(x)$  (it is possible to consider this term as possessing  $SU(3)$ -symmetry) then the constant  $a$  is real, and the quantities  $m_+^2$  and  $m_-^2$  are equal. The diagonalization of the mass term leads to the fields  $\Phi_1(x)$  and  $\Phi_2(x)$  with certain masses given by the expressions

$$\Phi_1(x) = \frac{1}{\sqrt{2}}[\Phi_{+1\frac{1}{2}-\frac{1}{2}}(x) + \Phi_{-1\frac{1}{2}+\frac{1}{2}}(x)], \quad \Phi_2(x) = \frac{1}{\sqrt{2}}[\Phi_{+1\frac{1}{2}-\frac{1}{2}}(x) - \Phi_{-1\frac{1}{2}+\frac{1}{2}}(x)], \quad (2)$$

whose form is the same for all nonzero values of the constants  $a$  and  $m_{\pm}^2$ . The definite values of the  $CP$ -parity of fields  $\Phi_1(x)$  and  $\Phi_2(x)$  are the result and not the ground for the formation of expressions (2).

Since the experiments indicate absence of definite values of  $CP$ -parity of the decaying neutral  $K$ -mesons, one should consider the case when the mass term in Lagrangian (1) does not possess the mentioned  $SU(3)$ -invariance. Then the first step of the appropriate procedure of Weinberg gives orthonormal fields  $\Phi_S(x)$  and  $\Phi_L(x)$  with definite masses  $m_S$  and  $m_L$  specified by the formulas

$$\Phi_S(x) = \frac{(1 - \varepsilon^*)\Phi_{+1\frac{1}{2}-\frac{1}{2}}(x) + (1 + \varepsilon^*)\Phi_{-1\frac{1}{2}+\frac{1}{2}}(x)}{\sqrt{2(1 + |\varepsilon|^2)}} = \frac{\Phi_1(x) - \varepsilon^*\Phi_2(x)}{\sqrt{1 + |\varepsilon|^2}}, \quad (3)$$

$$\Phi_L(x) = \frac{(1 + \varepsilon)\Phi_{+1\frac{1}{2}-\frac{1}{2}}(x) - (1 - \varepsilon)\Phi_{-1\frac{1}{2}+\frac{1}{2}}(x)}{\sqrt{2(1 + |\varepsilon|^2)}} = \frac{\varepsilon\Phi_1(x) + \Phi_2(x)}{\sqrt{1 + |\varepsilon|^2}}, \quad (4)$$

with

$$|m_L^2 - m_S^2| = \sqrt{(m_+^2 - m_-^2)^2 + 4|a|^2}, \quad (5)$$

$$\varepsilon = \frac{m_+^2 - m_-^2 + 2i\text{Im}a}{m_L^2 - m_S^2 - 2\text{Re}a}. \quad (6)$$

The next step of Weinberg's procedure consists in finding expressions for the fields  $\Phi_{\pm 1\frac{1}{2}\mp\frac{1}{2}}(x)$  through the fields  $\Phi_S(x)$  and  $\Phi_L(x)$  on the basis of the relations(3) and (4) and in substituting these expressions into all terms in the initial Lagrangian describing both strong and weak interactions.

Then, in completing the Weinberg's procedure, we should obtain Euler equations for each of the fields  $\Phi_S(x)$  and  $\Phi_L(x)$  from the transformed Lagrangian and perform the second quantization of the solutions of these equations, that would consist in identifying these solutions as vectors in the spaces of suitable irreducible representations of the Poincare group with neutral mesons  $K_S^0$  and  $K_L^0$ . As a result, the processes which were thought to be accompanied by the production or are caused by an interaction of one of the hypothetical  $K^0$ - and  $\bar{K}^0$ -bosons, with never being accompanied with the production or caused by an interaction of other one, can now proceed within the considered concept with involving both  $K_S^0$ - and  $K_L^0$ -bosons with almost equal probabilities (though, slightly different probabilities, that is important for a number of experiments). So, the production of  $\Lambda$ -hyperon in a  $\pi^-p$ -collision is accompanied with either  $K_S^0$ - or  $K_L^0$ -meson, with both of the latter being able to produce  $K^-$ -meson (when interacting with neutrons) and  $K^+$ -meson (when interacting with protons).

Fields  $\Phi_{\pm 1\frac{1}{2}\mp\frac{1}{2}}(x)$  and  $\Phi_{1,2}(x)$ , which are involved in mathematical operations to form the fields  $\Phi_S(x)$  and  $\Phi_L(x)$  and, that is especially important, to form the  $K_S^0$ - and  $K_L^0$ -mesons interaction constants, are not identified with any quanta at any step of such a formation.

Thus, the postulated universality of the Weinberg's prescriptions on the diagonalization of the mass term in the Lagrangian without increasing the total number of entities leads to the following conclusions:

- (1) The states  $K^0$  and  $\bar{K}^0$ , as physical objects (in the form of particles or "particle mixtures"), do not exist. Accordingly, the quark-antiquark bound states  $d\bar{s}$  and  $s\bar{d}$  are not realized;
- (2) The set of neutral  $K$ -mesons consists of two elements,  $K_S^0$  and  $K_L^0$ , which do not possess definite values of the third projection of the isospin. Accordingly, the bound states are formed only by the superpositions of quark-antiquark pairs  $d\bar{s}$  and  $s\bar{d}$  which are given by the expressions, obtainable in an obvious way from the formulas (3) and (4);
- (3) The antiparticles of the mesons  $K_S^0$  and  $K_L^0$  coincide with themselves;
- (4) In strong interactions involving neutral  $K$ -mesons, the isospin is not conserved;
- (5) The absence of the states  $K^0$  and  $\bar{K}^0$  destroys the ground for introducing the notion of their oscillations made by Pais and Piccioni [6].

All the listed conclusions about the family of neutral  $K$ -mesons should, in our view, also be extended to the sets of neutral  $D$ -,  $B$ - and  $B_s$ -mesons. In particular, each of these sets consists of two elements, namely,  $D_1^0$  and  $D_2^0$ ,  $B_H^0$  and  $B_L^0$ ,  $B_{sH}^0$  and  $B_{sL}^0$ , and the states  $D^0$  and  $\bar{D}^0$ ,  $B^0$  and  $\bar{B}^0$ ,  $B_s^0$  and  $\bar{B}_s^0$  do not exist.

The outlined concept of neutral mesons, precisely following the Weinberg's prescriptions on the transition from the initial gauge fields to the observed particles, is simple, elegant and consistent both in the theoretical and experimental aspects. None of its parts can serve as an analogy or basis for the hypothesis of neutrino oscillations. The radical difference between the judgements on the family of neutral  $K$ -mesons and the present day dominating judgements on the family of neutrinos start with the origin of nondiagonal mass terms in the Lagrangian of the initial fields and are strengthened by the total number of entities. Namely, such terms in the Lagrangian of neutral meson fields with isospin 1/2 are necessitated, as it was indicated above, by weak interactions, and the number of the initial and final meson fields remains the same. At the same time, the nondiagonal mass terms in the Lagrangian of the known neutrino fields are only arbitrarily introduced (see, e.g., [8]) to justify adding new entities, the massive neutrinos  $\nu_j$ ,  $j = 1, 2, 3$ , as "true particles", to justify declaring the known neutrinos  $\nu_\alpha$ ,  $\alpha = e, \mu, \tau$ , as "particle mixtures" and to realize the oscillation scenario a la Pais and Piccioni. It is worth noting that the "true particles"  $\nu_j$  do not directly participate in any production, scattering or absorption processes.

The redundancy of neutrino family inevitably leads to logical contradictions and uncertainties. Attempts to avoid some of the contradictions in the description of neutrino oscillations through the revision of quantum mechanics can be found, e.g., in the works [9] and [10].

We would now like to draw attention to only one essential logical aspect related to the concept of neutrino oscillations. Note in the beginning, that the realization of the notion of "particle mixtures", since the times of Pais and Piccioni [6] up to present day (see, e.g., [2]), contains the elements both quantum and classical mechanics. With respect to massive neutrino states whose superpositions correspond to the states describing the production of any of the known neutrinos  $\nu_\alpha$ ,  $\alpha = e, \mu, \tau$ , ones adopt the assumption (see, e.g., [2]), that each of them is described by its well-defined value of 4-momentum. Let us briefly elucidate the possible consequences of non-fulfilment of the specified assumptions.

It is accepted that the state vector  $|\nu_\alpha(t_0, \mathbf{r})\rangle$  of the neutrino  $\nu_\alpha$ , if exists, does not change in time, and that at the time  $t_0$  of the neutrino production it is linearly expressed through the state vectors of all neutrinos  $\nu_j$

$$|\nu_\alpha(t_0, \mathbf{r})\rangle = \sum_{j=1,2,3} u_{\alpha j} |\nu_j(t_0, \mathbf{r})\rangle, \quad \alpha = e, \mu, \tau, \quad (7)$$

where the coefficients  $u_{\alpha j}$  do not depend on the production conditions of the neutrino  $\nu_\alpha$ . As the state vector  $|\nu_j(t_0, \mathbf{r})\rangle$  belongs to the space of irreducible representations of the Poincare group characterized by the mass  $m_j$ , its dependence on the spatial coordinates determines the

distribution of the state over 3-momentum and thus specifies the evolution in time

$$|\nu_j(t, \mathbf{r})\rangle = \int |\nu_j(\mathbf{p})\rangle \exp[-i\sqrt{\mathbf{p}^2 + m_j^2}(t - t_0) + i\mathbf{p}\mathbf{r}] d^3\mathbf{p}. \quad (8)$$

Let the state of an evolving in time quantum-mechanical object identified at its production moment  $t_0$  with neutrinos  $\nu_\alpha$  be denoted as  $|Z_\alpha(t, \mathbf{r})\rangle$ :  $|Z_\alpha(t_0, \mathbf{r})\rangle = |\nu_\alpha(t_0, \mathbf{r})\rangle$ . On one hand, for any time  $t > t_0$  it is natural to describe this state by a time-dependent superposition of states presented in the right part of relation (7)

$$|Z_\alpha(t, \mathbf{r})\rangle = \sum_{j=1,2,3} u_{\alpha j} |\nu_j(t, \mathbf{r})\rangle. \quad (9)$$

On the other hand, the essence of the concept of neutrino oscillations is that the state  $|Z_\alpha(t, \mathbf{r})\rangle$ ,  $\alpha = e, \mu, \tau$ , is expressed as superposition of the three states  $|\nu_\beta(t_0, \mathbf{r})\rangle$

$$|Z_\alpha(t, \mathbf{r})\rangle = \sum_{\beta=e,\mu,\tau} v_{\alpha\beta}(t) |\nu_\beta(t_0, \mathbf{r})\rangle, \quad (10)$$

where  $v_{\alpha\beta}(t)$  are some  $c$ -number valued functions of time.

From relations (9), (8) and (7), we conclude that the equality (10) is feasible if and only if each of the three states  $|\nu_j(t, \mathbf{r})\rangle$  (8) is characterized by its definite the 3-momentum absolute value  $|\mathbf{p}_j|$ ,  $j = 1, 2, 3$ . If such a condition concerning the distributions of the massive neutrino states over 3-momentum is not fulfilled, that is likely enough from the field-theoretical point of view, then the realization of the concept of neutrino oscillations in such a situation becomes impossible, namely, the states of  $|Z_\alpha(t, \mathbf{r})\rangle$  for  $t > t_0$  are not representable as superpositions of the neutrino states  $\nu_e$ ,  $\nu_\mu$  and  $\nu_\tau$ . Because of that, we lose the possibility to calculate the rate of any expected process involving the object  $|Z_\alpha(t, \mathbf{r})\rangle$ .

Undoubtedly, an indicator of acceptability of some physical hypothesis is its capacity to explain some class of experiments. If an alternative description of this class of experiments appears, then the number of new entities and arbitrary parameters of both hypotheses lies on a bowl of scales.

The most meaningful experimental application of the neutrino oscillation hypothesis is aimed at solving the solar neutrino problem. It has been initiated by the work [8] in connection with negative results of Davis and others [11] on detecting the transitions  $^{37}\text{Cl} \rightarrow ^{37}\text{Ar}$ . Now we have results of five types of experiments with solar neutrinos: the transitions  $^{37}\text{Cl} \rightarrow ^{37}\text{Ar}$ , the transitions  $^{71}\text{Ga} \rightarrow ^{71}\text{Ge}$ , the elastic scattering on electrons, the disintegration of the deuteron by charged current and the disintegration of the deuteron by neutral currents (see review [2]).

We consider it necessary to note the following. First, as it is not possible to achieve a satisfactory solution to the solar neutrino problem by only using the hypothesis of the neutrino oscillation in vacuum, the mechanism of Wolfenstein, Mikheev and Smirnov comes into play, that involves significant influence of the Sun environment on the transitions of neutrinos from one type to another and has its own arbitrariness. Secondly, it is difficult, if at all possible, to find in the literature a summary of theoretical results for the rates of the processes of the types listed above that would be calculated on the basis of formulas of the neutrino oscillation model under some, recognized as optimal, values of its parameters.

45 years after its first emergence, the solar neutrino problem has received an alternative solution based on the hypothesis of the existence of semiweak interactions between electron neutrinos and nucleons mediated by (almost) massless pseudoscalar isoscalar boson, and the description of such interactions contains only one free parameter [12]. The relevant theoretical results are in good agreement with the results of four of the five listed above types of experiments with solar neutrinos. The rate of the deuteron disintegration by solar neutrinos induced by the

exchange of a massless pseudoscalar boson where the mass difference between the neutron and proton would have been taken into account remains yet not calculated.

Over a long time, many neutrino experiments are being in operation searching for a manifestation of neutrino oscillations. Among them, the KamLAND experiment with reactor antineutrinos is. There, the observed results differ significantly from the expected ones, that one explains by neutrino oscillations (see review [2]). In our work [13], an alternative explanation is given for this discrepancy, which is based on significant role of light attenuation in the KamLAND liquid scintillator, that has not been taken into account in theoretical calculations of the observability of expected events.

So, the present work together with the works [12] and [13] significantly narrows the theoretical and experimental base for the hypothesis of particle oscillations. It would be very desirable if it could stimulate a new comprehensive analysis of all calculations and conditions of the accomplished and running neutrino experiments.

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